Traffic generation with the SCANeR© II simulator : towards a multi-agent architecture

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Abstract

Renault has been developing driving simulators for over 10 years. They are used for ergonomics and advanced engineering studies at Renault as well as for road traffic research, human factor studies and driver training in different labs and companies in Europe (especially in France, the UK, Sweden and Norway). These simulators use SGI and/or PC image generation technology with up to 6 graphics channels and motion seat or platforms for kinaesthetic rendering. The real time simulation software, SCANeR© II version 1.3, currently includes -among others- simulation session initialisation and monitoring, vehicle dynamics, traffic generation, visual and kinaesthetic modules.

The traffic generation software allows the user (i.e. the experimenter) to describe and initiate real time traffic with autonomous vehicles. Up to several hundred vehicles can be rendered using a traffic management system and several state machines standing for the different vehicles. The SCANeR© II software has already been used in experimentation needing comprehensive scenarios or designed traffic situations.

One problem of the traditional approach is that some critical and/or complex situations are difficult to simulate. Such situations mainly occur when several vehicles want to have access to the same road and/or when the number of involved vehicles is important. Yet, for many years now, researches mainly conducted in distributed artificial intelligence have allowed to study systems characterised by intelligent autonomous entities. These entities, or agents, must be able to coordinate their actions in order to reach their goals. Such systems are named multi-agent systems.

Our work consists in modelling a road traffic as a multi-agent system and in studying the contribution of this approach. Vehicles have to cooperate and coordinate their actions in order to achieve their aims (to reach and to drive on roads) while avoiding endangering each other (accident risk).

In a driving simulator, autonomous vehicles must interact with each other and human beings (interactively driven vehicles). They constitute a traffic by anticipating, adapting and trying not to hinder one another. They must be able to communicate (via indicators, brake light, hazard lights, horn…) and cooperate (help each other) to behave in a coordinated way (to keep the traffic moving).

Implementing a road traffic as a multi-agent system may improve the realism of the simulated traffic and contribute towards the development of high level tools for traffic generation.
This article will be composed of three parts. The first part will propose a survey of traffic simulation approaches. The second part will describe the traffic generated with the SCANeR© II simulator. In the last part, techniques under implementation according to multi-agent principles are discussed.

Résumé

Contrairement à certains simulateurs de trafic routier, qui supportent un type de réseau spécifique ou des conditions courantes de circulation, celui du simulateur de conduite SCANeR© II de Renault vise la polyvalence. Une des difficultés est qu'il existe des situations complexes ou critiques auxquelles les véhicules se trouvent parfois confrontés (insertion sur autoroute saturée, accident obstruant une voie, etc.). C'est avec l'objectif de reproduire de telles conditions de circulation que nous portons aujourd'hui une attention particulière aux travaux issus de l'intelligence artificielle distribuée concernant les agents autonomes. En modélisant le trafic en tant que système multi-agents, il semble possible d'instaurer une véritable coordination des véhicules. Dans cet article, après un aperçu de la simulation de trafic routier, nous proposons une description du simulateur de trafic actuel de SCANeR© II et une présentation des développements en cours selon les principes du multi-agents.

INTRODUCTION

Simulation is today an effective tool used for reproducing and analysing a broad variety of complex problems, difficult to study by other means that might be too expensive or dangerous. This powerful tool is now of current use. The democratisation of new data processing techniques and the coming of inexpensive powerful computers has supported this move. Thus, it is in a favourable context that the interest for traffic simulation increased. Whether they are transport institutes, training centres, universities or car manufacturers, many research centres are active today in the field.

A SURVEY OF ROAD TRAFFIC SIMULATION

Traffic simulation is a dynamic problem associated with complex processes that cannot be easily described in an analytical way [1]. These processes are characterised by the interaction of several components of the system, named entities. The number of parameters is significant and the interactions are complex. Simulation models undertake to “mimic” the behaviour and the interactions of real entities (cars, trucks...) in order to reproduce –as accurately as possible- the behaviour of the system: the road traffic.

The user of a traffic simulation software specifies a scenario (the road network, the vehicles...) [2,3] as inputs of the model. Results provided are statistical and visual. Numerical results bring analysts quantitative and qualitative information referring to the evolution of the simulation. The visual representations are primarily used to give an idea about the state of the simulated environment.

FIELDS OF APPLICATION

With the emergence of driving simulators, traffic simulation [4] was regarded as essential, in particular through its influence on driving tasks (speed control, lane change manoeuvres…) and on mental load of the driver for ergonomics studies. Today its use is widening and reaches many fields.

The main fields for traffic simulation are:

- Design and improvement of car equipment
  The simulation is a powerful tool for evaluation. It enables saving time between validation and physical realisation (driving aid systems [5], headlights...).
- Training
  Real time simulation is increasingly used to educate and train personnel (traffic control centres) or for vehicle driving training (trucks [6], buses, cars...).
- Testing new structures
  Transportation facilities are costly investments. Simulation can be applied to quantify traffic performance according to different design options before the commitment of resources to construction (roads, real estate, tolls [7]...).
- Security and environment

Some applications in this field are: intelligent highways and intelligent vehicles studies [8], driver behaviour analysis in dangerous situation, accident reconstruction and exhaust fumes emissions level evaluation.

- Research

  Traffic simulation is used for mathematical and statistical studies with an aim at improving traffic-flow models [9]. It can also be used for the evaluation of alternative treatments by enabling to control the experimental environments and the range of conditions to be explored (signal control strategies, ATMS [10]...).

This compilation of applications shows the variety and scope of traffic simulation and is by no means exhaustive.

SIMULATION MODELS

Simulators and simulation models can be classified in accordance with several factors. Various approaches can depend on the specificity of the application and its constraints.

Time

Almost all the traffic simulation models describe dynamical systems; time is always the basic independent variable. Discrete models, unlike continuous models, represent real-world systems by asserting that their states change at points in time. There are two types of discrete models: *discrete time* models and *discrete event* models. Within each interval of time, discrete time models compute the activities that change the states of system elements. Discrete event models remain constant until a change of state occurs.

Level of detail

According to the level of detail chosen to represent the system that is under study, which mainly depends on the available computation power, a simulator is *macroscopic*, *mesoscopic* or *microscopic*.

A macroscopic model describes entities and their activities and interactions at a low level of detail. The traffic stream may be represented in some aggregate manner or by scalar values of flow rate and density. For example, individual lane changes are not represented; the model provides global quantitative or qualitative information [9].

A mesoscopic model generally represents most entities at a high level of detail but describes their activities and interactions at a lower level. For example, lane change manoeuvres are represented but could be performed as an instantaneous event [4].

A microscopic model describes most entities and their interactions at a high level of detail. For example, a lane change could invoke a car-following law with respect to its current leader, then with respect to its putative leader and follower in the target lane [8].

Deterministic model and stochastic model

When one wants to reproduce specific conditions or events, chance plays a major part. Two types of model are to be considered. Deterministic models have no random variables; all entity interactions are defined by exact relationships (mathematical or logical). On the contrary, stochastic models have processes which include probability functions. Deterministic models are well suited to experiments whose scenarios are intended to be completely reproductible. On the other hand, the behaviour of the vehicles may appear too mechanical and monotonous and realism is somehow lessened.

Design methodology

The design methodology used for the model may also be considered. A model can be programmed in a sequential way, as for some macroscopic simulators. It can also be designed according to object-oriented principles, as for many microscopic simulators. Today, another method is also used. This method, resulting from work carried out these last ten years in distributed artificial intelligence, is called the agent-oriented method.

The traffic generator of the SCANeR© II driving simulator was designed using an object-oriented method. The version currently used for the experiments is described in the second part of this article.

TRAFFIC GENERATION WITH THE SCANeR© II SIMULATOR

MODELING AND ARCHITECTURE

The main choices that guided the design of the simulation model for the autonomous traffic are shown below (see table 1).

The software architecture of Renault's SCANeR© II simulator is modular and made up of functional modules using a common communication protocol. Some modules can be dependent. Thus, *the traffic is the union of the interactively driven vehicle and the autonomous traffic* (see figure 1). The whole is managed by the module generating the autonomous vehicles and is supervised and controlled via the display module.

Design choice	SCANeR© II implementation
Model	Microscopic Discrete Time : can be set (default value is 20 Hz) Stochastic
Kinematics accuracy Dynamics accuracy (2D or 3D)	Yes No
Road geometry Highway support City environment support	3D Yes Yes
Vehicle types	Multiple : car, truck, motorcycle, bike, train, tram, pedestrian
Vehicle models Driver model	3 : trains & trams, two & four-wheelers with trailer support, pedestrians Unique, using risk parameters
Heterogeneous traffic	Simulates autonomous vehicles and takes the interactively-driven vehicle into account
Scenes record and replay 2D Visualization 3D Visualization	Yes Yes Yes (several views available)
Interactive scenario generation Traffic modification during play	Yes Yes
Development methodology Language Operating system	Object oriented C++ Windows NT (PC) or Unix (SGI)

Table 1 : Main design choices for the autonomous traffic generator of SCANeR© II

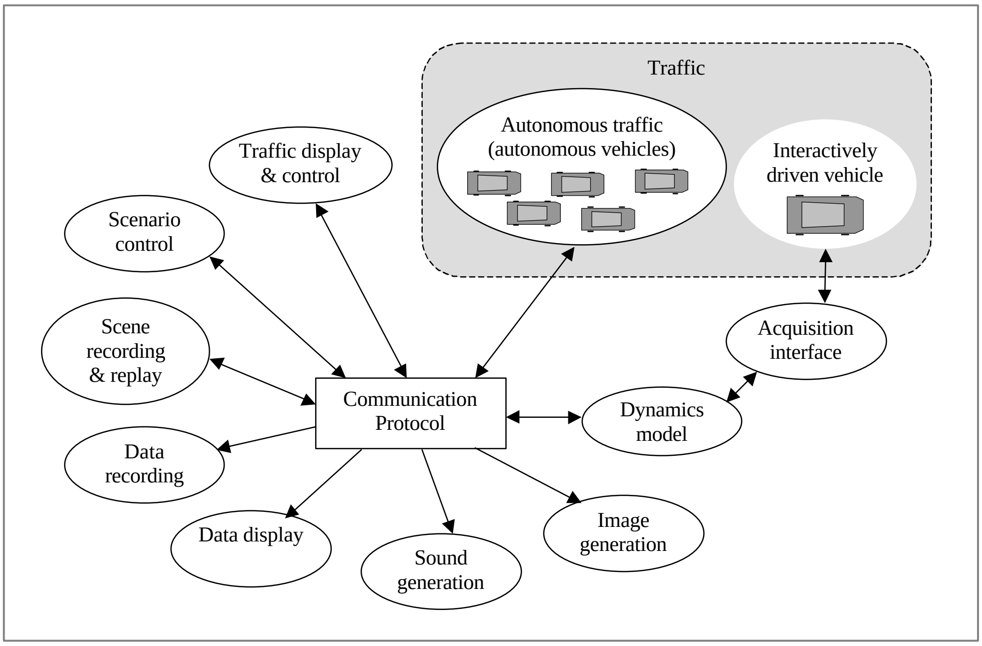

Figure 1: Software architecture of the driving simulator SCANeR© II.

The decrease in cost of personal computers and the increase in the capacity of networks enabled to fully benefit from this modularity [11]. The modules of SCANeR© II can be executed on various platforms (PC or SGI), each computer managing one or more modules. An advantage of this architecture is that when an experiment requires a relatively dense traffic (a few hundred vehicles), several traffic generation modules can be executed in parallel within the limits of the network capacity. Each one of these modules is supported by a different machine and manages a subset of vehicles.

AUTONOMOUS VEHICLES

SCANeR© II models a vehicle as a kinaematically accurate, two-axle, front-wheel-steered mechanism. Three vehicle models are provided, each one being associated with various physical types of vehicle (see table 1). The behaviour can be set thanks to parameters -corresponding to fixed limiting values (speed, acceleration, deceleration...)- and with risk factors (overtaking...). This approach allows a varied and animated traffic.

Functionally, all *intelligent vehicles are composed of three subsystems: perception, cognition and actuation*. This architecture has the advantage of describing both autonomous vehicles and interactively driven vehicles. Vehicles can perceive each other (position, speed, acceleration and direction), interact, reach available resources (lanes, roads, parking places) and interact with the simulated world (see figure 2).

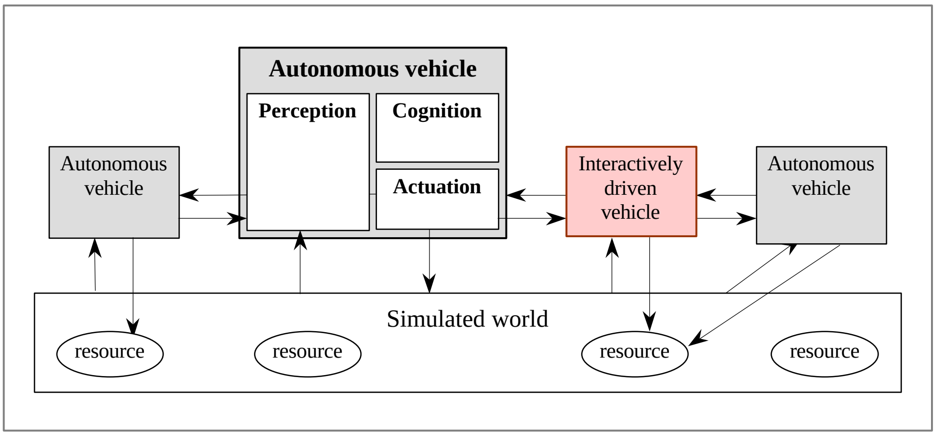

Figure 2: Structure of the vehicles composing the traffic.

▪ *Perception*

An autonomous vehicle acquires knowledge of the surrounding world in two stages. The first stage consists in scanning the road ahead to detect the possible changes in driving conditions (traffic lights and signs, pedestrian crossing, barriers…). The second stage relates to the perception of the other vehicles.
In SCANeR© II, perception is based on the road network since it is used for trajectory calculations and acquisition of information. The road network designer has to pay attention to the fact that he makes all the information available to the vehicles (road sections, signs positioning). Two vehicles know each other's status (position, speed, acceleration and direction). Autonomous vehicles also use the knowledge of the future route of the other vehicles to foresee their behaviour when approaching an intersection.

Once the useful information are obtained (road curve, signs and marking, position and trajectory relative to the perceived vehicles...), a vehicle goes into the cognition phase. This phase corresponds to the reasoning process and to the decision-making.

▪ *Cognition*

The cognitive process relative to the *driving task can be characterised as consisting of three decision levels: strategic, tactical and operational* [12]. A goal, which the vehicle must reach, is associated to each level. Each goal to realise implies a choice to achieve (see table 2). Each choice is then implemented while being based on the lower decision level and according to the constraints related to the vehicle's environment.

Level	**Goal**	**Choice**
Strategic	To plan route	Road
Tactical	To select manœuvre	Lane
Operational	To execute manœuvre	Speed & lateral offset

Table 2: Autonomous vehicle's driving task characterised as decision levels.

For example, the strategic goal –the route- of a vehicle driving on a highway can be to take the next exit towards a rest area. To fulfil its choice -the road-, the vehicle must, since it is on the left lane, take the tactical decision to cut in before the intersection.

At the highest level, autonomous vehicles must follow their route by taking into account the fixed constraints (speed limit of the vehicle, follow -or not- the Highway Code...). In SCANeR© II, the itinerary can be set before the simulation [3] or changed during the simulation (in a rule-based or random way).

The tactical level corresponds to the choice of short-term objectives combining the high level goals (route to achieve) and the constraints imposed by the lower level (physical characteristics of the vehicle, alignment of the road, traffic status). These objectives are mainly lane changes actualised in order to optimise the route between intersections.
For example (see figure 3 [13]), if vehicle A have to take the next exit and vehicle B strongly reduces its speed, then vehicle A must wonder whether it can change lane to overtake vehicle B.

Some traffic simulators, in a non driving simulation environment, neglect tactical-level simulation, generally because the need is relatively weak. On the other hand, it must be considered with the greatest attention for driving simulators. Actually, the autonomous vehicle behaviour depends on it and, consequently, the feeling of realism given to the driver of the interactive vehicle.
In SCANeR© II, all road types can be used for the simulation. As for the local environment, the direct leader and follower and the putative follower and leader on the target lane are included in the tactical reasoning process.

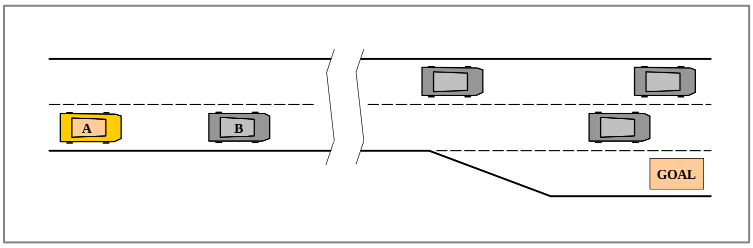

Figure 3: Example of situation requiring a tactical decision.

At the operational level, the vehicle determines the values that will allow it to realise what was decided in the tactical level. It is mainly a question of following an appropriate trajectory during the manoeuvre.
In the example, if vehicle A has decided to overtake vehicle B, it then calculates the speed and the relative lateral offset adapted with the execution of the lane-change manoeuvre (see figure 4).

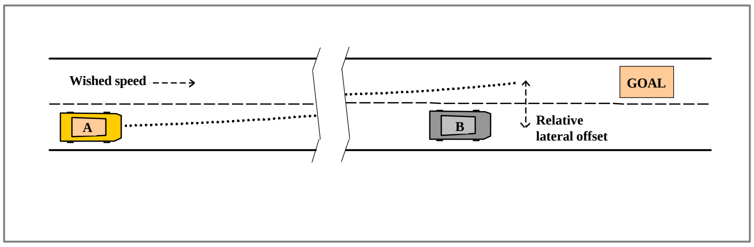

Figure 4: At the operational level, the vehicle executes the operation decided at the tactical level.

- *Actuation*

The subsystem corresponding to the actuation implements what was decided by the cognition subsystem in the operational level. Acceleration and the wheel angle are calculated. The vehicle can then move (see figure 5).

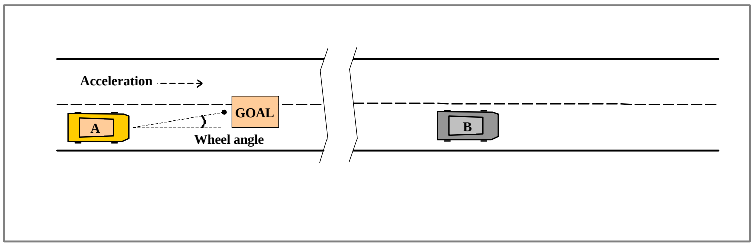

Figure 5: Within each cycle, the vehicle calculates its acceleration and its wheel angle.

In SCANeR© II, vehicles get the status of the other objects in the environment and perform their task while trying to avoid accident. This approach allows to reproduce traffic situations, such as those used for ergonomics and advanced engineering studies, while offering highly efficient real-time performances.

However, some experimentations need to reproduce more complex and/or critical situations (insertion on highway, accident, reduction of the number of lanes...). In such situations, conflicts between vehicles may appear and the flow stop some places whereas the conditions would not cause congestion in a real-world situation. It is with the objective to avoid this trouble that works made in distributed artificial intelligence (DAI), and in particular multi-agent systems (MAS), were taken into consideration.

TOWARDS A MULTI-AGENT ARCHITECTURE

TRAFFIC: A MULTI-AGENT SYSTEM

DAI is the group of computer science fields studying the behaviour of sets of entities with an aim at making them imitate the human intelligent behaviours. Road traffic simulation belongs to this field. A MAS is a set of software or human entities which coordinate their knowledge, goals and plans to act or solve problems, including the problem of the multi-agent coordination itself [14]. The intelligent entities composing the system are rational, autonomous agents capable of communication and action [15, 16].

In real-life traffic, an entity represented by a vehicle and its driver is an agent. In driving simulation, an autonomous vehicle (simulated vehicle and driver) and an inter-actively driven vehicle are both agents. In both cases, the traffic is a multi-agent system.

With the traditional approach, vehicles are endowed with an intelligence, autonomous and capable of actions *but* do not have real capacity of communication and cannot process the information they might receive. For example, a vehicle could not take into consideration that another vehicle uses its indicator. In this case, vehicles are what computer scientists call objects. The absence of communication between the vehicles implies an individualistic behaviour. This individualism penalises whole or part of the traffic. The vehicles are objects capable of movement but are not able to coordinate their knowledge and their goals to get over some of the encountered problems [17].

NEW DEVELOPMENTS

Our step consists in considering that a road traffic is -by definition- a MAS made up of physically distributed autonomous entities having specific characteristics (cars, trucks, buses, motorbikes...) and, consequently, different behaviours. These entities also have the capacity of perceiving their local environment and communicating with each other.

The first stage of our work is to model vehicles in order to take more physical and behavioural characteristics into account. For physical modelling, 2D dynamics accuracy might not impair real-time performances (engine speed and gear box). Concerning the behavioural models, the differentiation between four-wheeled and two-wheeled vehicles is necessary for realism. Also, advanced parameters for the driver model (psychological security distance, average latency at crossroads...) should be added.
These contributions make easier the creation of new vehicles as autonomous agents to allow the implementation of a more varied traffic.

The second stage consists of the implementation of a local perception. The road network need to be apprehended according to the local environment of the agent (vehicles ahead and road type). For the perception of the other vehicles, the interactively driven vehicle and the autonomous vehicles have to be identically considered. Thus, information to get concerning a perceived vehicle is the position, the trajectory and the lights status (brakes, direction...). The type of the vehicle (driven or autonomous) have not to be taken into account in order to support a process of homogeneous reasoning [18].

The third stage of our work is to conceive a realistic behaviour in its design and its execution. Even if the data are sometimes insufficient, even erroneous as in the real life, a perception based on visual information alone enables the vehicles to communicate their objectives. When a vehicle perceives surrounding vehicles' intentions, it is potentially able to act according to those. These intentions are related to a will of changing lane (i.e. to reach a resource). It is necessary to implement a structure that enables an agent to apprehend and answer any request concerning a resource access. If this resource is common, agents can cooperate to coordinate their actions [19, 20]. This enables to avoid a jam caused by a potential conflict situation.

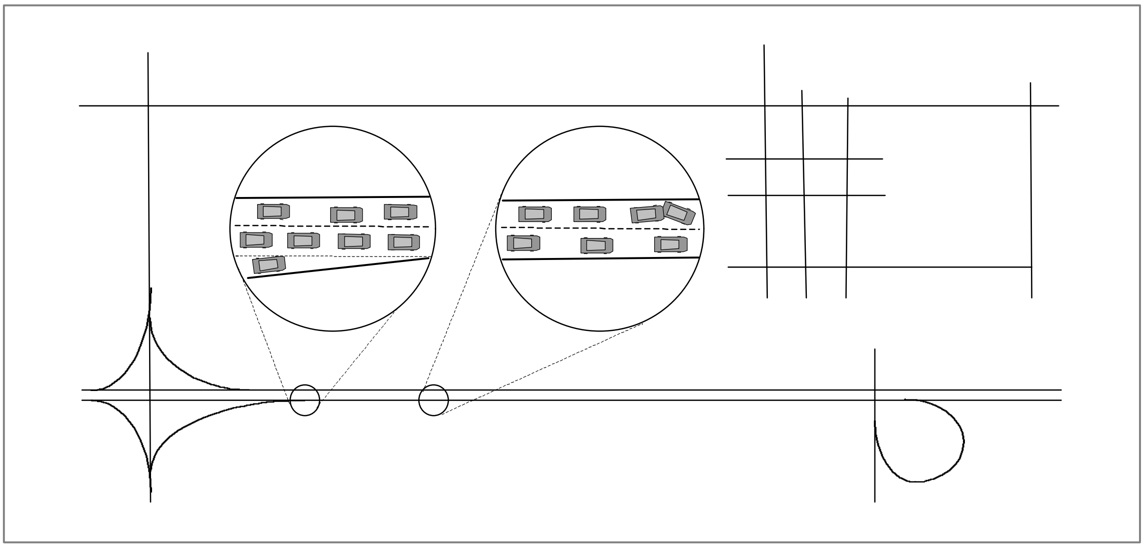

Figure 6: Examples of conflict situations requiring a coordination of actions.

As an example (see figure 6), an experiment may require a motorway network. It is therefore needed to simulate an insertion on a congested highway; the congestion may be caused by an accident which has occurred downstream.

If the vehicles observing the Highway Code do not have the capacity to cooperate, a conflict builds up related to the need for having access to a common resource: the right lane of the motorway in the insertion zone (see figure 7). The vehicles wishing to access the highway do not have priority and remain stuck on the access ramp.

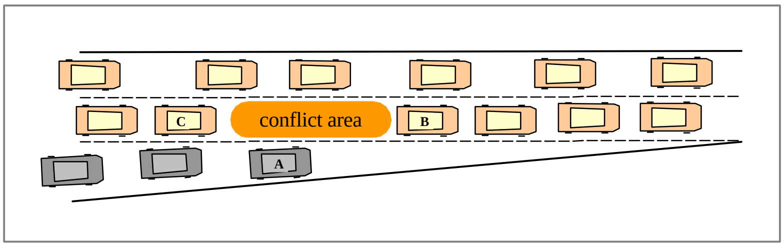

Figure 7: The access to a common resource creates a conflict zone.

In order to remedy this inertia, the first studies and developments were to set up a local perception for the agent. The existing architecture did not allow to build a cooperative behaviour immediately. Once the necessary minimum changes implemented, it was possible for us to develop a cooperation process. Schematically this process follows these three phases:

- vehicle A, wishing to reach a resource although it does not have priority, makes a request for co-operation by switching on its directional signal,
- vehicle C perceives A's request and decides to accept it -or not-
- if C accepts -it slows down- and if B is far away enough then A enters the highway;

  if C does not accept the request for cooperation then A waits until a vehicle following C accepts it.

More development -concerning the perception, the cognition and the number of cases to be considered- need to be done to implement a MAS approach but the first results are encouraging. Although the *agents* have a purely *reactive behaviour*, one can note the beginning of a *multi-agents coordination*. The flow of vehicles is strongly slowed down, which is normal, but does not stop.

CONCLUSION

During the simulation of complex situations, some difficulties appear. To solve them, the work completed in DAI/MAS was considered. Considering the traffic as a multi-agent system allows to simulate a more realistic ambient traffic even in complex situations by initiating a coordination of the traffic. The traffic can be coherent with an homogeneous integration of the interactively driven vehicle. Moreover, it is conceivable to develop dedicated tools for the creation of scenarios taking into account, not only the vehicles independently, but also the sets of vehicles with similar characteristics. The time devoted to the preparation of the experiments would then be reduced.

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